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TEST AND EVALUATION OF A MODIFIED LIQUID AIR GENERATOR

by

Dennis C. Follweiler

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NAVAL EXPLOSIVE ORDNANCE DISPOSAL FACILITY
INDIAN HEAD, MARYLAND 20640

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FOREWORD

[illegible] Development Department of the Naval Explosive Ordnance Disposal [illegible] the development of tools and equipment needed to support explo- [illegible] (EOD) personnel in the performance of their mission. In conjunction [illegible] program was initiated to provide naval EOD personnel with a self- [illegible] clothing set to be employed in hazardous environments created by the [illegible] chemical and biological agents.

A clothing set was developed by the Research and Development Department which [illegible] air to provide a cooling and breathing medium. Consequently, to effectively support the clothing set, a requirement existed for developing a means whereby EOD personnel could readily obtain liquid air. A liquid air generator was developed to provide the required support.

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ABSTRACT

A liquid air generator was procured from the Cryogenic Division of North American Philips Corporation and a test program was initiated. Some modifications were made to the generator based on the test results (NAVEODFAC Report 137). The modified generator was subjected to additional testing which is summarized in this report.

SUMMARY

A [illegible] liquid air generator was operated periodically from April 1970 through [illegible] permitting extended observation of its operation under a variety of weather conditions. Based on the problems encountered during testing, the following equipment modifications were recommended.

1. A dehumidifier should be designed to permit extended operating time between defrosting operations.

2. The chiller should be redesigned to permit operation in the temperature range of -45° to +120° F.

3. A number of modifications should be made to facilitate maintenance.

4. The storage tank should be modified to provide a better liquid level measuring system and composition control. Unnecessary piping and valves should be eliminated, and a means provided to increase the tank pressure for more rapid liquid transfer.

INTRODUCTION

[illegible] are required to perform operations on ordnance items in environments [illegible] by the presence of biological and chemical agents. A protective clothing [illegible] to provide EOD personnel protection from the effects of these agents. The [illegible] was developed employs liquid air as the source of cooling and uncontaminated [illegible].

A commercially available liquid air generator (developed to provide liquid air to support the protective clothing set) was purchased, tested, and modified. This modified unit was then subjected to additional testing. Based on these test programs and associated recommendations, the newly modified liquid air generator and storage tank will be functional for naval personnel using the protective clothing set.

TECHNICAL DISCUSSION

EQUIPMENT DESCRIPTION

The liquid air generator is designed to manufacture liquid air by condensing atmospheric air on a condensing plate. The plate is cooled by being placed in contact with helium at cryogenic temperatures.

The generator is composed of four subsystems—the cryogenerator, the water-cooling system, the chiller, and the control panel. A storage tank is provided to store the manufactured liquid air.

A simplified diagram of the cryogenerator is shown in Figure 1. The cryogenerator is directly involved in the manufacture of the liquid air. An electric motor drives a crankshaft which in turn causes two pistons (the displacer and compressor pistons) to move. The generator operates on the Stirling cycle which is shown in Figure 2.

The cycle begins with the upward travel of the compressor piston toward top dead center. The displacer remains stationary and, hence, the helium in the compression space is compressed. Some of the heat generated by the compression of the helium is removed by the cooling water which passes around the cylinder of the compression space.

At the start of the second stage of the cycle, the compressor piston has reached top dead center and the helium is exerting its maximum pressure. The displacer piston now begins to travel downward toward bottom dead center while the compressor piston remains stationary. The downward motion of the displacer piston unblocks a passageway between the compression space and expansion space. Thus, the compressed helium travels through the passageway and expands into the expansion space. While passing from the compression to the expansion space, it transfers more heat of compression to a regenerator where it is stored for use in another stage of the cycle. After passing through the regenerator, the helium expands into the expansion space which causes it to become cooler.

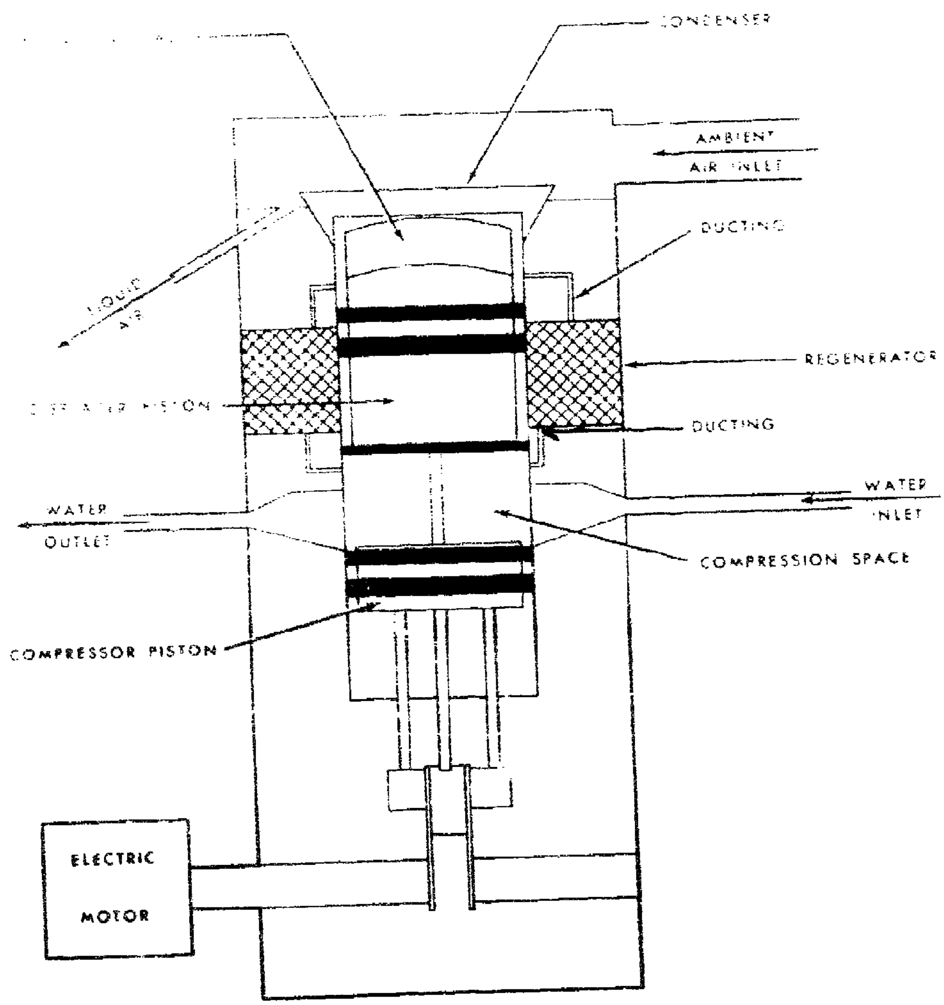

Figure 1. Schematic of the Cryogenerator.

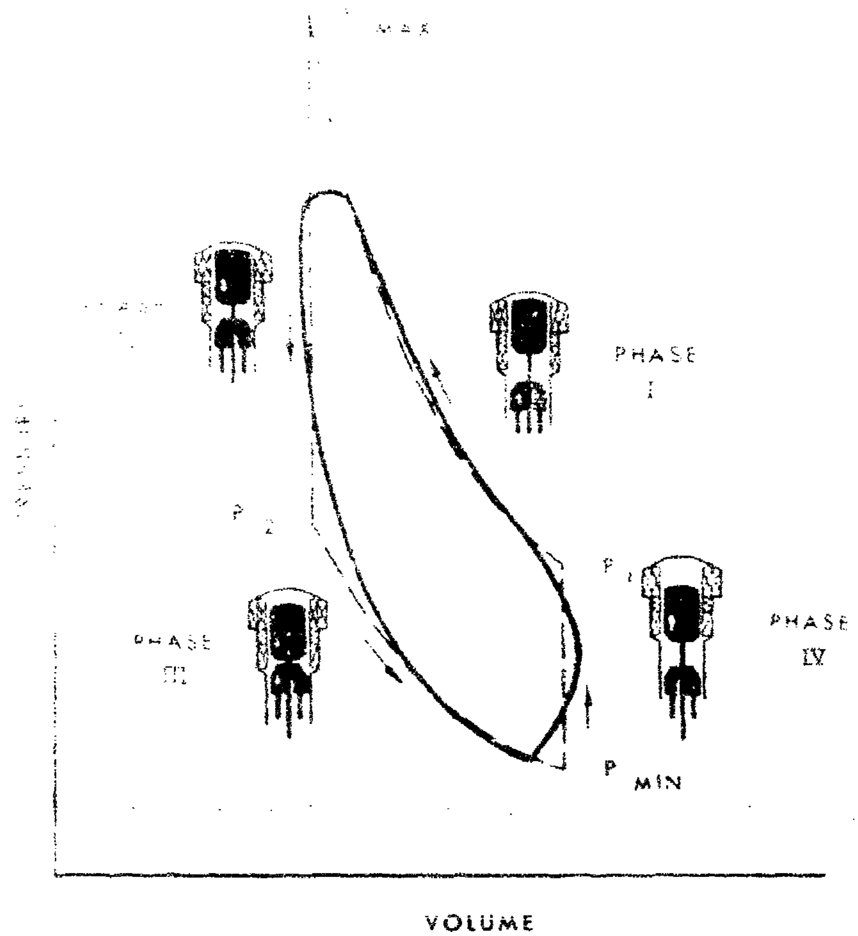

Figure 2. Typical Stirling Cycle.

The third stage of the cycle consists of a continued downward movement of the displacer piston accompanied by the compressor piston. This causes further cooling of the helium due to additional expansion. At the end of this stage of the cycle the displacer has reached bottom dead center, causing a minimum cycle pressure in the expansion space.

In the final stage of the cycle the displacer begins its return travel toward top dead center with the compressor piston remaining stationary. The upward movement of the displacer piston causes the helium in the expansion space to be displaced back through the regenerator to the compression space. While passing through the regenerator, it absorbs the heat that was stored there on the second stage of the cycle. This completes one cycle of operation. A P-V diagram of a cycle is given in Figure 2.

The cold helium in the expansion space is in contact with a piece of metal called the condenser. The cold helium cools the condenser to such a temperature that incoming, ambient air condenses to a liquid when it comes into contact with the condenser. As the air is drawn into the cryogenerator, it passes through an ice and water separator where some of the moisture is removed. A vacuum line serves to remove noncondensable gases from the header.

[illegible] system that utilizes the expansion of freon [illegible] transfer is accomplished in a counterflow heat [illegible] cooling water and carries it to a condenser [illegible] blowing air over the refrigerant. See Figure 3.

[illegible] control switches which control and [illegible]

[illegible] 200 liter capacity [illegible] oxygen enrichment occurs.

[illegible]

[illegible] April 1970 through 23 May 1972, the modified liquid air [illegible] was operated periodically to determine the effects of various environments on equip- [illegible] attention was given to ease of maintenance and operation and the [illegible] of nitrogen and oxygen in the storage tank.

[illegible]

[illegible] Appendix A, the generator ceased operating [illegible] 30 occasions during the [illegible] period. Twenty (or 66%) of the stoppages were the result of a high vacuum being created [illegible] header. This is caused by a buildup of frost and ice within the header. With restricted air flow, the vacuum line removing the noncondensable gases causes excess vacuum in the header and the generator automatically ceases operation. The heating of the cooling water caused six out of 30 (or 20%) of the shutdowns. This was caused by an insufficient quantity of freon being in the chiller. This is a normal air conditioner problem and is easily avoided by proper maintenance. The frosting of the header caused two out of 30 (or 7%) of failures. This is caused by buildup of frost around the header and is dependent on ambient humidity. The water lite-on condition caused two out of 30 (or 7%) of failures. This was caused by failure of the water pump to operate when needed to circulate the water. However, the cause of this failure was unknown and the machine restarted immediately upon depression of the start button.

The storage tank was tested for both the length of time it would hold the charge and the variation in the liquid air composition. The composition is of concern since liquid nitrogen boils at -320° F, while liquid oxygen boils at -297° F. Consequently, the nitrogen boils off first leaving an increasing amount of liquid oxygen. This is undesirable due to the combustion supporting properties of oxygen.

The average length of time that the storage tank would hold a full charge of liquid air was 13 days and during this period, the oxygen concentration never fell below 21 percent nor exceeded 28 percent.

CONCLUSION

On the basis of the test results, it was concluded that a dehumidifier should be installed. The incoming air would then be dehumidified ensuring a longer operating time before the cryo-generator would have to be shut down and defrosted due to moisture accumulation and freezing.

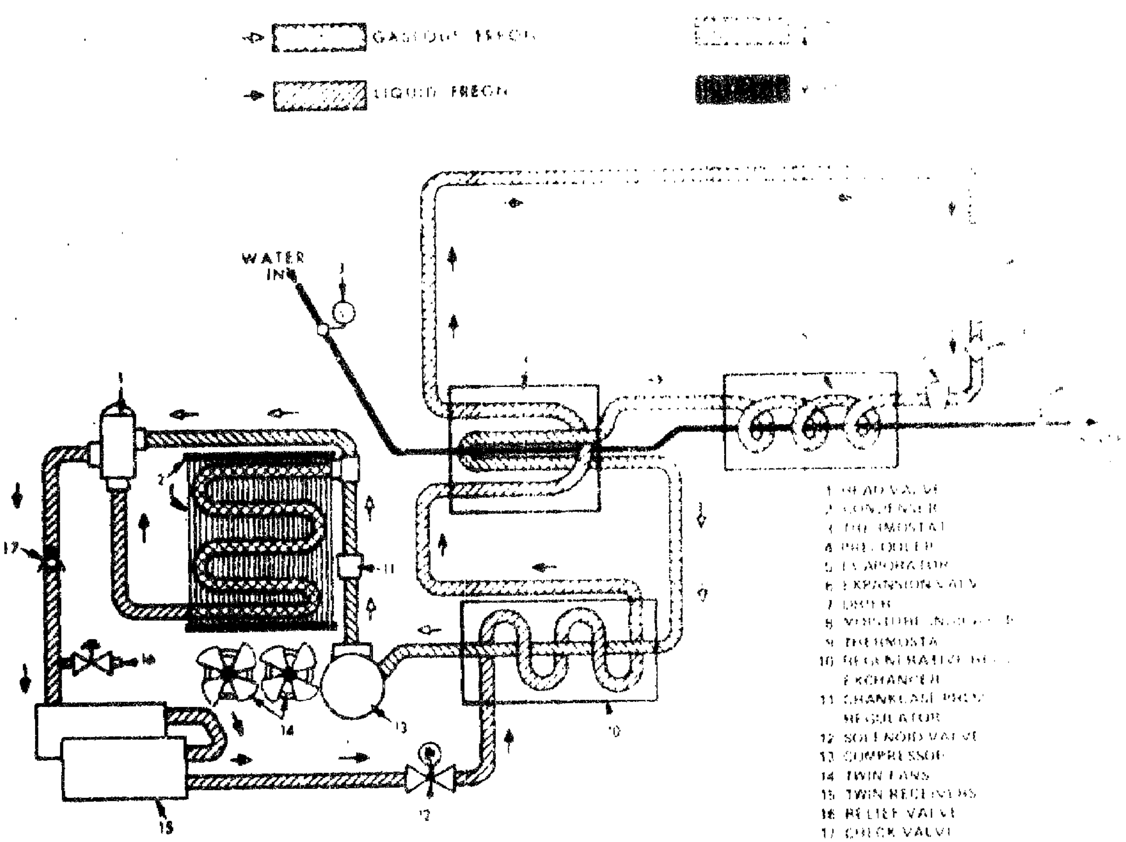

Figure 5. Chiller Flow Diagram.

Various plumbing changes should be effected to facilitate maintenance. These changes consist primarily of rerouting piping, wiring, etc.

The storage tank should have an improved tank level gage since, on occasion, the existing one would stick. Also, unnecessary plumbing should be removed from the tank.

Once the above changes are accomplished, the equipment should be ready for fleet deployment.

APPENDIX A

SUMMARY OF CRYOGENERATOR PROBLEMS

AMBIENT CONDITIONS TEMPERATURE		RELATIVE HUMIDITY	HELIUM PRESSURE (psi)	DATE	PROBLEM
			[illegible]	[illegible]	[illegible]
			[illegible]	[illegible]	[illegible]
			[illegible]	[illegible]	[illegible]
			[illegible]	[illegible]	Vacuum light
			[illegible]	[illegible]	Functioned OK
			[illegible]	[illegible]	Vacuum light in a.m. Functioned OK in p.m.
			[illegible]	[illegible]	Vacuum light
			[illegible]	[illegible]	Temperature high
			[illegible]	[illegible]	Temperature high
			[illegible]	[illegible]	Temperature high
			[illegible]	[illegible]	Vacuum light
			[illegible]	[illegible]	Vacuum and temperature
			[illegible]	[illegible]	Temperature high
			[illegible]	[illegible]	Power failure
			[illegible]	[illegible]	Temperature high
			322	5/27/70	Vacuum light
			[illegible]	5/29/70	Vacuum light
[illegible]	[illegible]		325	6/01/70	Vacuum and H_2O
[illegible]	[illegible]		302	6/02/70	Vacuum
[illegible]	[illegible]		302	6/03/70	OK
94	70		298	6/04/70	OK
[illegible]	[illegible]		300	6/05/70	OK
[illegible]	[illegible]		295	6/08/70	OK
			295	6/09/70	OK
[illegible]	[illegible]		294	6/10/70	Vacuum light
[illegible]	[illegible]		297	6/11/70	OK
[illegible]	[illegible]		287	6/15/70	OK
92	69	—	293	6/16/70	OK
95	72	78	295	6/17/70	OK
100	72	85	298	6/18/70	OK
87	64	76	319	6/22/70	OK
86	62	75	324	6/23/70	OK
94	62	35	309	7/06/70	OK
98	70	54	313	7/07/70	OK
94	74	60	312	7/08/70	OK
96	63	82	323	8/17/70	Vacuum
97	63	83	304	8/18/70	Vacuum
94	70	84	278	8/19/70	Vacuum
95	66	83	289	8/20/70	Vacuum
92	68	60	288	8/25/70	Vacuum
94	70	82	330	8/26/70	OK

SUMMARY OF CRYOGENERATOR PROBLEMS (Continued)

AMBIENT CONDITIONS					
TEMPERATURE (°F)		RELATIVE HUMIDITY (%)	HELIUM PRESSURE (psi)	DATE	PROBLEM
[illegible]	LOW				
				[illegible]	[illegible]
			[illegible]	[illegible]	[illegible]
			[illegible]	[illegible]	[illegible]
			[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	OK
		[illegible]	[illegible]	[illegible]	Vacuum
		[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	OK
		[illegible]	[illegible]	[illegible]	Vacuum
	[illegible]	[illegible]	317	9/16/70	Vacuum
[illegible]	[illegible]	[illegible]	[illegible]	9/17/70	OK
		[illegible]	[illegible]	9/18/70	OK Tank Full
		[illegible]	[illegible]	[illegible]	OK
[illegible]	[illegible]	[illegible]	[illegible]	10/06/70	OK
		[illegible]	[illegible]	[illegible]	Tank Full
		[illegible]	[illegible]	[illegible]	OK
	[illegible]	[illegible]	[illegible]	[illegible]	OK Tank Full
[illegible]	[illegible]		337	[illegible]	OK
[illegible]	[illegible]		338	[illegible]	OK
[illegible]	[illegible]		324	11/30/70	H_2O off
[illegible]	48	[illegible]	325	12/01/70	
[illegible]	46	–	346	12/02/70	
–	–	–	–	1/11/71	Chiller repair
	30	–	324	1/13/71	Defrost header
[illegible]	32	–	312	1/14/71	Helium leak
34	10	92	317	3/03/71	
44	32	52	308	3/04/71	
54	34	–	311		OK
62	36	–	316	3/30/71	OK
80	48	–	319		OK
80	48	–	319	4/01/71	OK
78	48	–	322	4/02/71	OK
68	43	–	319	4/15/71	OK
73	55	–	323	4/16/71	OK
86	50	–	324	4/21/71	OK
–	–	–	314	4/22/71	OK
63	46	–	320	4/22/71	OK
82	54	–	318	5/10/71	OK
90	64	–	320	5/11/71	OK
–	–	–	328	6/30/71	H_2O off
100	74	72	316		OK
99	82	78	320	6/30/71	OK

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KEY WORDS	LINK A		LINK B		LINK C	
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[illegible] Air						
[illegible] Ordnance Disposal						
Protective Clothing						
[illegible] Agents						
[illegible] Agents						